that assist with either directing flow in a direction different than the direction of net flow through the microchannel (that is, different than the direction of the length of a microchannel) or create flow rotation. The features increase surface area and create convective flow that brings fluids to a microchannel wall through advection rather than diffusion. Flow patterns may swirl, rotate, tumble and have other irregular and or chaotic patterns—although the flow pattern is not required to be chaotic and in some cases may appear quite regular. The flow patterns are stable with time, although they may also undergo secondary transient rotations. The surface features are preferably at oblique angles—neither parallel nor perpendicular to the direction of net flow past a surface. Surface features may be orthogonal, that is at a 90 degree angle, to the direction of flow, but are preferably angled. The active surface features are further preferably defined by more than one angle along the width of the microchannel at least at one axial location. The two or more sides of the surface features may be physically connected or disconnected. The one or more angles along the width of the microchannel act to preferentially push and pull the fluid out of the straight laminar streamlines. For embodiments in which it is necessary to compare heat transfer to a flat channel, all surface features may be defined as recessed.

[0106] "Across the gap mixing" refers to mixing streams within a micro-channel in the direction that is perpendicular to the bulk flow; in channels with a rectangular cross-section this term refers to mixing across the gap between the two major surfaces. This is accomplished by placing the surface features on both major surfaces of the micro-channel. Design principles to achieve this type of mixing, include: (1) Provide a substantially angled component to the direction of the surface feature run length relative to the mean direction of the bulk flow in the main channel. Velocity in the main channel near the upstream end of each surface feature leg will tend to be higher than near the downstream end of each surface feature leg. Coordination between surface feature patterns in the top and bottom walls can act to increase the perpendicular component to the velocity vector and thus have a greater effect of reducing external mass transfer resistance when lateral mixing is not a strong consideration. For example, with surface features recessed into opposing walls, using a "cis" configuration may be preferred over a "trans" active surface feature configuration in preventing the formation of one or more cores of flow in the bulk which are not as easily swept into the active surface features. (2) Provide an adequate number of adjacent features such that the fluid is moved across the entire channel gap. More angles, bends, twists, or otherwise direction changes within an individual surface feature will act to move or mix flow across a channel but may not be preferable for increasing the fraction of residence time that a feature spends within the active surface features. It is preferable to have more than one angle in one or more surface features along the width of a microchannel in at least one axial location, where the features across the width may or may not be physically connected. The alignment of adjacent features or nested angles will also act to pull fluid laterally across the channel. (3) Provide multiple repeated substantially similar or "like" features along the flow length for any given microchannel wall. The repetition of similar features along the flow length maintains the non-straight (i.e. swirling) flow patterns in the main channel as flow proceeds down the channel length.

[0107] Multiple features may be included within any given microchannel, including features that recess at different depths into a microchannel wall or walls. Preferably, the spacing between recesses is in the range of 0.05 mm to 10 mm, more preferably in the range of 0.1 to 1 mm. The surface features may be present all throughout the microchannel or for a portion. The portion of area having surface features may be intermittent so as to promote a desired reaction or unit operation in tailored zones. As an example, a 2.5 cm section of a microchannel may have a tightly spaced array of surface features, followed by 10 cm of a flat channel, and then followed still by a 5 cm section of loosely spaced surface features. Loosely spaced refers to surface features with a pitch or feature to feature distance more than 5× the run width of the surface feature.

[0108] In some embodiments, the surface features extend substantially over the length of a microchannel (not including any flow distribution or manifolding sections). In some embodiments, a microchannel can have surface features over 50% or less of its length, in some embodiments over 20% or less of its length, and in some embodiments 10 to 100% of the microchannel length. In some embodiments, it may be preferable to include surface features within a manifolding or flow distribution section as well to promote or tailor heat transfer or to tailor flow distribution by modifying the pressure drop in some channels or sections to tailor flow distribution.

[0109] Superior mixing and performance in unit operations can be obtained by combining across the width mixing features with across the gap mixing features. To provide total mixing the two design principles can be used in concert with one another. Desirable features include: placing surface features on opposing channel walls; configuring the features on any one face to allow the fluid the move back and forth across the channel width; and aligning the surface feature inlets on one face with the surface feature inlets on the opposite face. That is to say, preferentially coordinating the features between the top and bottom plates such that the pattern on the two faces are substantially "cis" in orientation relative to each other rather than "trans".

[0110] In one preferable embodiment, an array of similar surface features with a chevron or check mark pattern are disposed on one wall and a similar array of similar features aligned at either the same angle or a substantially inverted angle (180 degrees transposition) creates a particularly useful pattern for moving flow and molecules inside the active surface features and increasing the time spent within the active surface features disproportionately as the Reynolds number increases.

[0111] The minimum number of like features preferably placed in series along the channel length depends on the channel gap and surface feature depth. Similar or "like" features are replicates of each other placed adjacent to each other along the channel length. An example is illustrated in FIG. **1***b*. The flow patterns set up by these features is not considered turbulent flow, especially out in the bulk flow. The flow is better described as "directed laminar" flow.

[0112] The surface features may have two or more layers stacked on top of each other or intertwined in a 3-dimensional pattern. The pattern in each discrete layer may be the same or different. Flow may rotate or advect in each layer or only in one layer. Sub-layers (defined as not adjacent to the